

HISTORY OF FRACTURE MECHANICS

COLLABORATION BETWEEN THE PHYSICOMECHANICAL INSTITUTE OF THE UKRAINIAN NATIONAL ACADEMY OF SCIENCES AND THE FGUP OF THE DESIGN OFFICE OF CHEMICAL AUTOMATICS IN THE FIELD OF CREATION OF OXYGEN-HYDROGEN LIQUID-PROPELLANT ENGINES

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UDC 620.193.55:669.15

The collaboration between the Design Office of Chemical Automatics dealing with the design and production of liquid-propellant rocket engines and the Karpenko Physicomechanical Institute, a recognized scientific leader in the field of physicochemical mechanics of materials, began in 1976 from discussions on the interesting results of fatigue tests of structural materials with protective coatings under the conditions of high-frequency ($f \sim 20$ kHz) loading obtained in the Design Office of Chemical Automatics. The high scientific level of the discussion of the presented results stimulated the mutual interest in the solution of scientific and technical problems put forward to both collectives and, naturally, led to the revelation of the points of joint application of forces.

In the early 1970s, the Design Office of Chemical Automatics began to develop an RD0120 powerful oxygen-hydrogen engine for the space "Énergiya-Buran" complex and was in urgent need of information on the serviceability of structural materials in a medium of high-pressure gaseous hydrogen. At that time, the Physicomechanical Institute had accumulated sufficient experience in the investigation of the serviceability of structural materials in hydrogen-containing oil and gas media, had advanced testing and methodological data, considerable experience in the design of nonstandard test equipment, and, first of all, highly skilled scientific personnel. In the discussions of leaders and specialists of both organizations, the principal direction of collaboration was revealed, namely: the formation of a powerful research center based on the Physicomechanical Institute that would be able to carry out complex investigations of the influence of hydrogen on physicomechanical characteristics of materials under conditions simulating the temperature-force loading of structural materials. The leaders of the Ukrainian Academy of Sciences and the Ministry of General Engineering of the USSR supported this idea and made a common decision on the formation of the Interdepartmental Research Center "Proton."

On the basis of its own experience, information from leading research centers, and the specification of the Design Office of Chemical Automatics, the Physicomechanical Institute designed and launched a laboratory complex equipped with unique test equipment of its own design and production, which enables one to carry out experiments with ultrapure hydrogen at a pressure up to 120 MPa in the temperature range from 20 to 1273 K. In this work, K. B. Katsov, V. I. Tkachev, and other employees took an active part under the guidance of V. V. Panasyuk.

In the course of joint works performed according to the coordinated program, more than thirty sorts of promising material were investigated, the characteristics of short-term and long-term strength under tension and two-axial loading, low- and high-cycle fatigue, and resistance to the action of thermal cycles were obtained, and cyclic crack resistance and "hydrogen degradation" were studied [1]. The researchers determined the criterial parameters of "hydrogen degradation" of composite materials, which characterize the serviceability of structural elements and are used in strength analysis, and developed and experimentally verified the methods of evaluation of strength and durability of structures (including structures containing defects) operating in hydrogen [2]. The dependences of mechanical characteristics on temperature, pressure of gaseous hydrogen, loading rate, preliminary saturation, and presence of contaminating impurities in hydrogen were investigated and systematized [3, 4], and the influence of various metallic, oxide, and nitride barrier coatings was checked [5].

Design Office of Chemical Automatics, Voronezh, Russia. Translated from *Fizyko-Khimichna Mekhanika Materialiv*, Vol. 37, No. 2, pp. 179–180, March–April, 2001. Original article submitted February 22, 2001.

These works enabled one to select the following group of materials: steels with stable and metastable austenitic structure, nickel-iron alloys of medium and high strength containing nickel or its equivalent up to 45%, and a number of alloys based on copper and aluminum (and, under certain conditions, based on titanium) slightly embrittled with hydrogen. Moreover, metallurgical technologies improving the hydrogen resistance of structural materials were developed, and the specific requirements to technological processes, which form the structural state of structural elements, were formulated.

Investigations performed in the Interdepartmental Center "Proton" enabled one to select and substantiate the applicability of composite materials to operation in gaseous high-pressure hydrogen and to successfully complete the creation of an RD0120 powerful pollution-free liquid-propellant rocket engine of a new generation. The Physicomechanical Institute not only was engaged with the problems of substantiation of the applicability of composite materials in aggregates of the fuel line and carried out the control-delivery tests of certain commercial parts, but also rendered practical assistance in the introduction of nondestructive methods of control over electroplated coatings on large-sized units of the engine, development of certain methods of analysis of the stress-strain state of structural elements, and training of highly skilled scientific personnel for the metallurgical service of the Design Office.

The results of the joint work were published in several tens of papers, reported at international conferences on hydrogen power engineering and fracture mechanics, and presented in monographs and joint inventions. The atmosphere of close businesslike collaboration and mutually beneficial partnership formed under these conditions has helped our collectives to preserve the high scientific-technical potential and to take new steps in the investigation of the "hydrogen-metal" system, which opens the way for environment-friendly power engineering in the XXI century. Among the significant achievements of the last years, it is worth noting the development of a method for prevention of premature failures of power installations using hydrogen as a working medium, which are caused by reversible hydrogen brittleness [6], and, in the context of the new liquid-propellant rocket engine (space towboat), the investigation of resistance of materials with high strength-to-weight ratio to hydrogen embrittlement. At present, despite the evident advantages of these materials, their use in similar power installations is still restricted. Without doubt, the existing union of high science and technique will give result in unprecedented progress for mankind.

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